

## ENGINEERING PROPERTIES OF CURED SMALL AND BELLARY ONIONS

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### ABSTRACT

Onion (*Allium cepa* L.) is one of the oldest bulb crops, known to mankind and consumed worldwide. It is one of the most important commercial vegetable crops grown in India. Despite the achievements in onion processing and storage, the versatility of onions grown in India desperately requires clear database of physical, frictional and textural properties for better and precise designing of post-harvest operations like grading, sorting and packaging. The sample size taken is 50 bulbs under each grade and the measured properties include equatorial diameter, polar diameter, neck diameter, geometric mean diameter ( $D_{GM}$ ), arithmetic mean diameter ( $D_{am}$ ), frontal surface area ( $A_{FS}$ ), cross-sectional area ( $A_{CS}$ ), mass, volume, density, co-efficient of friction, cutting strength and TSS. Small onions (CO-3) and Bellary onions though differ in their physiology, the shape index of bulbs are spherical in nature. Neck thickness of CO-3onions is  $0.29 \pm 0.13$  and Bellary onion is  $0.68 \pm 0.34$  cm. The density of both the onions ranged from  $0.95 \pm 0.09$  to  $1.05 \pm 0.07$  g/cm<sup>3</sup>. Bellary onions weigh at least  $108.47 \pm 21.14$  to  $129.52 \pm 33.65$  g whereas CO-3onion contains 8-10 number of bulbs per clump with mass of around 75 g. The Geometric mean diameter ( $D_{GM}$ ) are  $2.51 \pm 0.42$  to  $6.20 \pm 0.28$  cm, arithmetic mean diameter ranged from ( $D_{am}$ )  $2.54 \pm 0.429$  to  $6.25 \pm 0.27$  cm, frontal surface area ( $A_{FS}$ ) ranged from  $6.15 \pm 1.886$  to  $32.693 \pm 2.734$  cm<sup>2</sup>, cross-sectional area ( $A_{cs}$ ) from  $5.21 \pm 1.60$  to  $30.74 \pm 2.70$  cm<sup>2</sup> for CO-3 and Bellary onions respectively. Though the values of  $D_{GM}$  AND  $D_{am}$  are close to each other the geometric mean gives a normalized mean for the study. The cutting strength of CO-3 onions and Bellary onions are  $62.71 \pm 15.18$  and  $129.52 \pm 33.65$  N. Co-efficient of friction and rolling angle ranged from  $0.25 \pm 0.05$  to  $0.27 \pm 0.06$  and  $11.13 \pm 1.23$  to  $11.98 \pm 3.15$ ; the total soluble solids of CO-3 onions is 15°Brix which gives promising storage attributes in comparison to 12°Brix in Bellary onions. The redness value of the onions is not significantly different for both and ranged between  $12.24 \pm 2.40$  to  $14.84 \pm 1.43$ .

**KEYWORDS:** Onion, Engineering Properties, Cutting load, Penetration Strength, Co-Efficient of Friction

### INTRODUCTION

Onion (*Allium cepa* L.) is one of the oldest bulb crops, known to mankind and consumed worldwide. It is one of the most important commercial vegetable crop grown in India and believed to be originated in Central Asia. It is valued for its distinct pungent flavour and is an essential ingredient for the cuisine of many regions. Onion is the queen of the kitchen (Selvaraj, 1976).

India ranks second in the production of onions next to china. It contributes about 19.25 % of total world production (FAO, 2012). The compound annual growth rate of production area, is steadily increasing from 1974-75 to 2011-12 by 3.36 % to 5.95 %, production by 4.94 % to 7.07 % and productivity by 0.51 to 3.4 % respectively. According to FAO 2011 statistics, productivity of country is 14.35 T/ha which is at least 5 times less compared to Republic of Korea

(66.16 T/ha), about 4 times less than USA (56.13 T/ha), Spain (55.21 T/ha), Netherland (51.64 T/ha) and Myanmar (46.64 T/ha) (Chengappa *et al.*, 2012)

Onion is cultivated throughout India; during 2012-13 the area of cultivation is 0.992 million hectares with production of 16.65 million metric tonnes. Maharashtra's standalone contribution is 32.6 % in total production and the rest shared by Karnataka, Gujarat and Madhya Pradesh in India (NHRDF, 2012). Given that India is bestowed with varied agro-climatic conditions it is not only possible to grow different crops but also it supports different varieties of same crop. Engineering properties aid in design and development of equipment for use during the post-harvest operations of onions like grading, sorting or packaging. Keeping this in view, the main objective of the study was to determine physical, mechanical and textural properties to form a database for the popular onion varieties Nasik Bellary and CO-3multiplier.

## MATERIALS AND METHODS

### Materials

Bellary onions (*Allium cepa* L.) are purchased from the onion commission mundy, Trichy and multiplier CO-3(*Allium cepa* var *aggregatum*) from Onion farms, Perambalur.

### Grading

Onions must be from the cultivar of *Allium cepa* and shall possess general features like intact sound bulbs, devoid of diseases or rotting symptoms, clean and free from visible foreign matters, free from frost damage, sufficiently dry without hollow or tough stems, free from pest, pest damage and abnormal external moisture and also devoid of any foreign smell and taste. Nasik Bellary onions of size above 6.00 cm falls under extra big and less than 2.00 cm to be graded as small. For small onions of size above 3.50 cm is graded large and those falls in the range of 2.50 – 3.50 cm is considered medium and below 2.50 cm as graded as small. CO-3 multiplier onion varieties does not produce large grade onion bunches.

### Linear Dimensions

There are two categories of onion bulb diameter: polar diameter and equatorial diameter and are measured by vernier calliper. Polar diameter is the distance between the onion crown and the point of root attachment to the onion. Equatorial diameter is the maximum width of the onion in a plane perpendicular to the polar diameter. The equatorial diameter ( $D_e$ ), polar diameter ( $D_p$ ), and thickness ( $T$ ), of each bulbs from each variety were measured with a caliper reading to 0.001 cm accuracy. The geometric mean diameter ( $D_{gm}$ ), arithmetic mean diameter ( $D_{am}$ ), volume ( $V$ ), frontal surface ( $A_{fs}$ ) and cross-sectional of areas ( $A_{cs}$ ) of the bulbs were calculated using the following relationships given by Mohsenin (1970), as follows:

$$\text{Geometric mean diameter}(D_{gm}) = (D_e D_p T)^{0.333}, \text{ cm} \quad (2.1)$$

$$\text{Arithmetic mean diameter}(D_{am}) = \frac{(D_e D_p T)}{3}, \text{ cm} \quad (2.2)$$

$$\text{Frontal surface area}(A_{fs}) = \frac{\pi}{4} D_e D_p, \text{ cm}^2 \quad (2.3)$$

$$\text{Cross sectional area}(A_{cs}) = \frac{\pi (D_e + D_p + T)^2}{4 \cdot 9}, \text{cm}^2 \quad (2.4)$$

### Shape Index

Shape index is used to evaluate the shape of onion bulbs and it is calculated according to the following (Abd Alla, 1993) equation

$$\text{Shape index} = \frac{D_e}{\sqrt{(D_p * T)}} \quad (2.5)$$

The onion bulb is considered as oval if the shape index >1.5, on the other hand, it is considered spherical if the shape index <1.5.

### Moisture Content

The moisture content of randomly selected onion bulbs from a 10 kg sample was determined according to ASAE standard (1984). Three samples of each variety bulbs were randomly selected and weighed on an electronic balance to a precision of 0.001 g.

### Volume and Density

The real density of samples was determined by the water displacement method. Fifteen bulbs of each sample were weighed and each one was dropped, separately into a 1000 ml measuring cylinder filled with distilled water up to 500 ml. The rise in water indicated the true volume of the bulbs. From the mass and the true volume of the bulbs, the real density was calculated. For each case, the determination was replicated four times and the mean was considered (Mohsenin, 1970)

## MECHANICAL PROPERTY

### Coefficient of Static Friction

Coefficient of static friction (COF) is the ratio of the force required to slide the bulb over a surface divided by the normal force pressing the bulb against the surface. The coefficient of friction was the tangent of the slope angle of the table measured with a protractor (Oje & Ugbor, 1991).

To determine the rolling angle, the onion bulb to be tested was kept on the selected surface, in the most stable position to prevent toppling over (top upwards). Then by rotating the handle at minimum speed, the platform was inclined until the onion bulb began to roll. At this position, the turning of the handle was stopped and the angle of inclination of the platform was read (Bahnasawy et al, 2004)

## TEXTURAL PROPERTIES

### Cutting Strength

Firmness of the vegetable cubes was measured using a texture analyzer (Stable Microsystems Texture Analyser) with a TA-42 knife probe with 45° chisel blade. A 50-kg load cell was used for all texture measurements. The pretest speed was 0.3 cm/s, the test speed was 0.25 cm/s, and the posttest speed was 1 cm/s. The cutting of onion is performed both in polar and equatorial axis (Koskineemi et al, 2013)

### Puncture or Penetration Load

Puncture load is the force required for pushing a probe into a product to a depth that causes irreversible crushing. It was given as an indicator of the mechanical strength of the onion to withstand mechanical harvesting and postharvest handling. Head of a flat-end probe (0.3 cm diameter) was used to measure the puncture resistance of the onion bulb (Bahnasawy et al, 2004)

### Colour Measurements

The colors of onions were measured using Hunter Lab Colorimeter. The instrument was calibrated with a white, black and green plate. Color of onion bulbs are measured in terms of lightness (L), redness to greenness ( $a^*$ ), yellowness to blueness ( $b^*$ ) on all possible axis and average of those value is taken as the color of the bulb. Hue angle ( $H^\circ$ ), chroma (C), chroma difference ( $\Delta C$ ) and total colour difference ( $\Delta E$ ) were calculated using the following equations

$$\Delta L^* = \text{difference in lightness/darkness value} \quad (2.6)$$

$$+ = \text{lighter} = \text{darker}$$

$$\Delta a^* = \text{difference in red/green axis} \quad (2.7)$$

$$+ = \text{red} - = \text{green}$$

$$\Delta b^* = \text{difference in yellow/blue axis} \quad (2.8)$$

$$+ = \text{yellow} - = \text{blue}$$

$$C = \sqrt{a^{*2} + b^{*2}} \quad (2.9)$$

$$\Delta C^* = \text{difference in chroma} \quad (2.10)$$

$$+ = \text{bright} - = \text{dull}$$

$$H = \tan^{-1} \frac{b^*}{a^*} \quad \text{when } a^* > 0 \text{ and } b^* = 0 \quad (2.11)$$

$$H^\circ = 180^\circ + \tan^{-1} \frac{b^*}{a^*} \quad \text{when } a^* < 0 \quad (2.12)$$

$$H = 360^\circ + \tan^{-1} \frac{b^*}{a^*} \quad \text{when } a^* > 0 \text{ and } b^* < 0 \quad (2.13)$$

$$E = \sqrt{L^{*2} + a^{*2} + b^{*2}} \quad (2.14)$$

Statistical analysis was carried out according to Frennd and Lihell (1981). Multiple linear regression for Tables 1, 2 and 3 are done to find the best fit relation among the measured properties. Mean, standard deviation (SD) and coefficient of variation (CV) are also calculated (Table 1-3). Colorimetric values are analysed for paired t-test.

## RESULTS AND DISCUSSIONS

### Physical Properties

#### Relationship between Equatorial Diameter, Polar Diameter, Shape Index, Volume and Density

Size and shape are inseparable in a physical object and both are generally necessary to describe the irregular shape of fruits and vegetables. Abd Alla, (1993) found the shape index of onion bulbs using the polar and equatorial diameter. Shape index of the chosen Bellary and CO-3 onions irrespective of grades fall in spherical shape. The lower neck thickness of the bulbs ensures low microbial contamination and transpiration loss. Volume change is also an important parameters in estimating the shrinking of onions during storage. To predict volume, the independent values of polar and equatorial diameters of onions bulbs are related (Griffith and Smith, 1964). It is found that linear regression with Pearson's correlation attempts to predict the volume ranged between 92 – 94 % for CO-3 onion and 82-99 % for Bellary onions. (Subscript L, M and S represents grade large, medium and small; BO and SO stands for Bellary and small onions)

$$V_{M-SO} = -4.51 + 8.40 D_e - 3.36 D_p, R^2 = 0.92 \quad (3.1)$$

$$V_{S-SO} = -6.44 - 4.41 D_e + 9.72 D_p, R^2 = 0.94 \quad (3.2)$$

$$V_{L-BO} = -368.95 + 45.45 D_e + 30.30 D_p, R^2 = 0.99 \quad (3.3)$$

$$V_{M-BO} = -128.59 + 25.97 D_e + 12.38 D_p, R^2 = 0.82 \quad (3.4)$$

Table 1 shows the mean values of medium and small sized CO-3 multiplier onions, equatorial and polar diameters, neck thickness ranged from  $2.12 \pm 0.41$ ,  $2.97 \pm 0.38$  and  $0.29 \pm 0.13$  cm and the volume and density ranged from  $5.00 \pm 4.30$  to  $5.9 \pm 0.87$  cm<sup>3</sup>;  $1.04 \pm 0.09$  to  $0.95 \pm 0.09$  cm<sup>3</sup> respectively. Bellary onions of grades large and medium ranged from  $5.79 \pm 0.49$ ,  $7.20 \pm 0.33$  and  $0.68 \pm 0.34$  cm and the volume and density ranged from  $92.50 \pm 19.79$  to  $133.33 \pm 25.16$  cm<sup>3</sup>;  $0.99 \pm 0.04$  to  $1.05 \pm 0.07$  cm<sup>3</sup> respectively.

#### Relationship between Geometric Mean Diameter ( $D_{GM}$ ), Arithmetic Mean Diameter ( $D_{AM}$ ), Frontal Surface Area ( $A_{FS}$ ), Cross-Sectional Area ( $A_{CS}$ ), and Mass

Mass of the onions bulbs are important quality parameter and the surface areas of fruits and vegetables are important in investigations related to spray coverage, removal of residues, respiration rate, light reflectance, and colour evaluation, as well as in heat transfer studies in heating and cooling processes (Mohsenin, 1970). Frechette and Zahradnik, 1966 related the weight and surface area of the McIntosh apples and found the correlation coefficient of 97.50%. Baten and Marshall, 1943 developed numerous equations to calculate weight by surface area measurements which is corresponding to specific fruit cultivar of apples, pear and plums. Onion bulbs mass is predicted using the multiple linear regression equation involving geometric mean diameter ( $D_{gm}$ ), arithmetic mean diameter ( $D_{am}$ ), frontal surface area ( $A_{fs}$ ) and cross-sectional area ( $A_{cs}$ ). It is found that linear regression with pearson's correlation attempts to predict the mass ranged between 89 – 90 % for CO-3onion and 78-86 % for Bellary onions.

$$M_{M-SO} = 3.37 - 26.48 D_{gm} + 2.91 A_{cs} + 0.10 A_{fs}, R^2 = 0.89 \quad (3.5)$$

$$M_{S-SO} = 0.65 - 14.57 D_{gm} + 1.89 A_{cs} - 0.16 A_{fs}, R^2 = 0.90 \quad (3.6)$$

$$M_{L-BO} = -862.86 - 443.53 A_{cs} + 156.48 A_{fs}, R^2 = 0.86 \quad (3.7)$$

$$M_{M-BO} = 351.42 - 61.46 D_{gm} + 10.83 A_{cs} + 7.50 A_{fs}, R^2 = 0.77 \quad (3.8)$$

Table 2 shows the geometric mean diameter ( $D_{gm}$ ) ranged from  $2.26 \pm 0.38$  to  $2.51 \pm 0.42$  cm, arithmetic mean diameter ranged from ( $D_{am}$ )  $2.32 \pm 0.36$  to  $2.54 \pm 0.42$  cm, frontal surface area ( $A_{fs}$ ) ranged from  $5.03 \pm 1.48$  to  $6.15 \pm 1.88$  cm<sup>2</sup>, cross-sectional area ( $A_{cs}$ ) from  $4.33 \pm 1.34$  to  $5.21 \pm 1.60$  cm<sup>2</sup> and the mass ranged from  $6.23 \pm 3.19$  to  $7.81 \pm 3.19$  g for medium and small grade CO-3onions. For Bellary onions the geometric mean diameter ( $D_{gm}$ ) ranged from  $5.60 \pm 0.41$  to  $6.20 \pm 0.28$  cm, arithmetic mean diameter ranged from ( $D_{am}$ )  $5.62 \pm 0.41$  to  $6.25 \pm 0.27$  cm, frontal surface area ( $A_{fs}$ ) ranged from  $24.97 \pm 3.76$  to  $32.69 \pm 2.73$  cm<sup>2</sup>, cross-sectional area ( $A_{cs}$ ) from  $24.97 \pm 3.76$  to  $30.74 \pm 2.70$  cm<sup>2</sup> and the mass ranged from  $88.58 \pm 17.43$  to  $132.41 \pm 27.00$  g.

## TEXTURAL PROPERTIES

### Relationship between Cutting Strength (CS) and Penetration Force (PN) With Moisture Content, TSS and COF Forco-3and Bellary Onion Bulbs

Moisture content of onion decreases from the core to the outermost layer. Moisture content of CO-3and Bellary onions papery layer, first layer, and core moisture ranges from 0.17 to 0.10, 8 to 25, 83 to 89% w.b. respectively. The onion requires higher cutting strength for low core moisture onions and vice versa. The relation of cutting and moisture content are

$$CS_{M-SO} = 438.56 - 4.55 MC, R^2 = 0.98 \quad (3.9)$$

$$CS_{S-SO} = 258.80 - 2.33 MC, R^2 = 0.94 \quad (3.10)$$

$$CS_{L-BO} = 1650.15 - 18.39 MC, R^2 = 0.97 \quad (3.11)$$

$$CS_{M-BO} = 760.55 - 7.79 MC, R^2 = 0.80 \quad (3.12)$$

It is found that linear regression with pearson's correlation attempts to predict the cutting strength (CS) ranged between 94 – 98 % for CO-3onion and 80-97% for Bellary onions. The TSS of the CO-3onions are about 14-15 % and cutting strength ranged from  $62.71 \pm 15.18$  to  $50.10 \pm 9.68$  N. Bellary onion TSS ranged between 11-12 % and cutting strength ranged from  $108.47 \pm 21.14$  to  $129.52 \pm 33.65$  N. Penetration strength of onions shows inverse relation with the cutting strength. The probe (P/2N) needle used for penetration is exposed to very small surface area of onion and thus it takes lesser force to penetrate than the cutting probe. The relation of penetration and moisture content are

$$PN_{M-SO} = 198.04 - 16.46 MC, R^2 = 0.99 \quad (3.13)$$

$$PN_{S-SO} = 15.89 - 0.11 MC, R^2 = 0.80 \quad (3.14)$$

$$PN_{L-BO} = 23.06 - 0.21 MC, R^2 = 0.61 \quad (3.15)$$

$$PN_{M-BO} = 37.87 - 0.38 MC, R^2 = 0.84 \quad (3.16)$$

It is found that linear regression with pearson's correlation attempts to predict the penetration strength (PN) ranged between 80 – 99 % for CO-3onion and 61-84 % for Bellary onions. The penetration strength of CO-3and Bellary onion ranged between  $5.20 \pm 0.91$  to  $6.07 \pm 1.38$  N respectively.

Co-efficient of friction and rolling angle of the CO-3 and Bellary onions ranged from  $0.25 \pm 0.05$  to  $0.27 \pm 0.06$  and  $11.13 \pm 1.23$  to  $11.98 \pm 3.15$  respectively. The closer range of the rolling angle value implies that it is not possible to sort the onions based on the rolling angle. This result was in agreement with Bahnasawy et al, 2004

### Colorimetric Properties

Table 4 shows the total colour difference ( $\Delta E$ ) for CO-3 and Bellary onion bulbs to be 6.68 to 10.31. Artes et al. (2000) used  $\Delta E$  to follow color changes during degreening of citrus. The disadvantage with  $\Delta E$  is that they give no indication of the direction of the color change. The value of H represents the angle of hue. The positive  $\Delta a^*$  and  $\Delta b^*$  values represent the first quadrant in standard colour chart. The hue angle of the CO-3 and Bellary onions ranged between  $29.94 \pm 13.03$  to  $34.20 \pm 12.43$  respectively. These values correspond to red colour, while the positive chrome ( $\Delta C$ ) values indicate the brighter red colour i.e. pink shade of onions in the chrome chart.

T-test for colour of onions is performed to know that the colour changes in grades are significant or not. CO-3 onions grade medium has higher colour value than large and the changes are significant whereas in Bellary onions the colour change in grade large and medium are not significant.

### CONCLUSIONS

Onion polar and equatorial diameter are the important factors in developing the prediction model for volume and mass of bulbs. The TSS of the CO-3 onions ranged from 14-15 °Brix has more potential for storage than that of the Bellary onions which has only 11-12 °Brix. The thinner neck diameter ensures proper curing of the onions. Moisture of the onion plays an important role in determining the cutting and penetration strength. Linear regression for cutting/penetration strength in relation with moisture content and is satisfactorily correlated. The cutting strength of the onion is in inverse relationship with penetration strength of the bulbs. Colorimetric values of onions suggest that they fall in the bright red region of standard chart.

### REFERENCES

1. Abd Alla, H. S. (1993). Effect of coating process on seeds viability and some physio-mechanical properties of Egyptian cotton. *J. Agric. Sci. Mansoura Univ.*, 18(8), 2384–2396.
2. Artes, F., Marin, J. G., Porras, I., and Martinez, J. A. (2000). Evolution de la Calidad de limón, pomelo y naranja durante la desverdización. *Iberoamericana Tecnología Postcosecha*. 1(2): 71–79.
3. ASAE standard (1984). ASAE 5352.1. Moisture measurement. American Society of Agric. Eng. 2950 Niles Road, St. Joseph, MI 49085-9659.
4. Bahnasawy A.H, Z.A. El-Haddad, M.Y. El-Ansary, H.M. Sorour. (2004) Physical and mechanical properties of some Egyptian onion cultivars *Journal of Food Engineering* 62 :255–261
5. Baten W. D. & R. E. Marshall. 1943. Some methods for approximate prediction of surface area of fruits. *J. Agricultural Research* 66(10):357-373.
6. Chengappa P G, Manjunatha A V, Vikas Dimble, Khalil Shah. (2012). Competitive Assessment of Onion Markets in India. Institute for Social and Economic Change. Competition commission of India.
7. Frechette, R. J. & J. W. Zahradnik, (1966). Surface area-weight relationship for McIntosh apples.

8. Frennd, R. J., & Lihell, R. C. (1981). SAS for linear models. Cary, NC: SAS institute.
9. Griffiths, J. S., & C. M. Smith, 1964. Relationship between volume and axes of some quartzite pebbles from the olean conglomerate rock city, New York. Am. J. of Sci.262(4):497-512
10. Koskiniemi B Craig, Van-Den Truong, Roger F. McFeeters, Josip Simunovic, (2013). Quality evaluation of packaged acidified vegetables subjected to continuous microwave pasteurization LWT - Food Science and Technology 54: 157-164
11. Maw, B. W., Hung, Y. C., Tollner, E. W., Smittle, D. A., & Mullinix, B. G. (1996). Physical and mechanical properties of fresh and stored sweet onions. Trans. ASAE, 39(2), 633–637.
12. Mohsenin, N. N. (1970). Physical properties of plant and animal materials. New York: Gordon and Breach, pp. 51–87, 889.
13. National horticultural research and development board. (2012). www.nhrdf.com. Date accessed on 01.03.14
14. Oje, K., & Ugbor, E. C. (1991). Some physical properties of oil bean seed. J. Agric. Eng. Res., 50, 305–313.
15. Selvaraj, s., (1976), Onion: Queen of the kitchen. *Kisan World*, 3(12): 32-34

## APPENDICES

**Table 1: Relationship between Mean Equatorial Diameter, Polar Diameter, Shape Index, Volume and Density of CO-3and Bellary Onion Bulbs**

Variety	Equatorial Diameter A, (Cm)	Polar Diameter B, (Cm)	Shape Index	Volume (Cm <sup>3</sup> )	Density (G/Cm <sup>3</sup> )
<b>Co-3(Multiplier) – Grade Medium</b>					
Mean	2.70	2.82	1.11	5.9	1.04
SD	0.51	0.44	0.08	0.87	0.09
CV (%)	19.14	15.83	7.72	14.84	9.50
Correlation with volume-v	0.94	0.80	-	1.0	-
<b>CO-3(Multiplier) – Grade Small</b>					
Mean	2.12	2.97	0.89	5	0.95
SD	0.41	0.38	0.07	4.30	0.094
CV (%)	19.73	13.07	7.99	86.02	9.80
Correlation with volume-v	0.97	0.95	-	1.0	-
<b>Bellary– Grade Large</b>					
Mean	7.20	5.77	1.24	133.33	1.05
SD	0.33	0.34	0.07	25.16	0.07
CV (%)	4.64	5.89	6.36	18.87	7.16
Correlation with volume-v	0.96	0.88	-	1.0	-
<b>Bellary – Grade Medium</b>					
Mean	5.79	5.53	1.05	92.5	0.99
SD	0.49	0.50	0.11	19.79	0.04
CV (%)	8.59	9.15	10.80	21.39	4.93
Correlation with volume-v	0.87	0.56	-	1.0	-

**Table 2: Relationship Between Geometric Mean Diameter ( $D_{gm}$ ), Arithmetic Mean Diameter ( $D_{am}$ ), Frontal Surface Area ( $A_{fs}$ ), Cross-Sectional Area ( $a_{cs}$ ), Mass and Density of the CO-3and Bellary Onion Bulbs**

Variety	$D_{gm}$ , c (cm)	$D_{am}$ , d (cm)	$A_{fs}$ , e (cm <sup>2</sup> )	$A_{cs}$ , f (cm <sup>2</sup> )	Mass, g (g)
<b>CO-3(Multiplier) – Grade Medium</b>					
Mean	2.51	2.54	6.15	5.21	7.81
SD	0.42	0.42	1.88	1.60	3.19
CV (%)	17.08	16.88	30.67	30.76	40.92
Correlation with mass- g	0.94	0.91	0.93	0.88	1.0
<b>CO-3(Multiplier) – Grade Small</b>					
Mean	2.25	2.32	5.03	4.33	5.84
SD	0.38	0.36	1.48	1.34	3.19
CV (%)	16.95	15.91	29.53	31.07	40.92
Correlation with mass- g	0.92	0.93	0.93	0.91	1.0
<b>Bellary – Grade Large</b>					
Mean	6.20	6.25	32.69	30.74	132.41
SD	0.28	0.27	2.73	2.70	27.00
CV (%)	4.58	4.45	8.36	8.78	20.39
Correlation with mass- g	0.45	0.49	0.49	0.60	1.0
<b>Bellary – Grade Medium</b>					
Mean	5.60	5.62	25.25	24.97	88.58
SD	0.41	0.41	3.64	3.76	17.43
CV (%)	7.46	7.42	14.44	15.09	19.68
Correlation with mass- g	0.77	0.78	0.79	0.48	1.0

**Table 3: Relationship between Cutting Strength and Penetration Force with Moisture Content, TSS and COF for CO-3and Bellary Onion Bulbs**

Variety	Brix (%)	COF	Rolling Angle	Moisture Content, MC (Wb)	Cutting Strength, CS (N)	Penetration Force, PN (N)
<b>Co-3(Multiplier) – Grade Medium</b>						
Mean	14.39	0.24	11.19	83.19	59.34	6.07
SD	0.56	0.02	2.14	1.83	8.38	1.38
CV (%)	3.92	0.10	1.76	2.19	14.13	22.86
Correlation with CS	-	-	-	0.99	1.0	-
Correlation with PN	-	-	-	0.99	-	1.0
<b>CO-3(Multiplier) – Grade Small</b>						
Mean	15.37	0.27	11.13	84.14	62.68	5.55
SD	0.33	0.06	1.23	6.33	15.19	1.66
CV (%)	2.14	0.23	1.89	7.52	24.23	0.29
Correlation with CS	-	-	-	0.97	1.0	-
Correlation with PN	-	-	-	0.80	-	1.0
<b>Bellary – Grade Large</b>						
Mean	11.0	0.25	11.98	83.19	128.22	5.22
SD	11.4	0.05	3.15	1.82	30.12	0.91
CV (%)	12.0	21.10	1.76	2.19	23.49	17.44
Correlation with CS	-	-	-	0.98	1.0	-
Correlation with PN	-	-	-	0.78	-	1.0
<b>Bellary – Grade Medium</b>						
Mean	12.1	0.22	11.75	83.69	108.47	6.00

Table 3: Contd.,						
SD	12.0	0.074	2.17	2.44	21.14	1.01
CV (%)	12.2	32.63	1.31	2.91	19.49	16.85
Correlation with CS	-	-	-	0.89	1.0	-
Correlation with PN	-	-	-	0.91	-	1.0

Table 4: Colour Values of CO-3and Bellary Onion Bulbs

Variety	L*	A*	B*	C	H	$\Delta L^*$	$\Delta a^*$	$\Delta b^*$	$\Delta E$
<b>Co-3 (Multiplier) – Grade Medium</b>									
Mean	37.05	11.99	8.14	14.49	34.20				
SD	6.00	1.05	4.30	3.14	12.43				
CV (%)	16.20	8.79	52.78	21.67	36.34				
<b>CO-3 (Multiplier) – Grade Small</b>						-1.59	2.43	1.33	6.86
Mean	35.47	14.42	9.48	17.32	33.56				
SD	2.78	1.64	0.98	1.05	5.29				
CV (%)	7.83	11.39	10.31	6.05	15.75				
$\Delta C$	-	-	-	2.83	-				
$\Delta H$	-	-	-	-	0.64				
<b>Bellary– Grade Large</b>									
Mean	27.74	12.93	8.26	14.81	29.94				
SD	7.56	3.35	3.70	4.44	13.03				
CV (%)	27.24	25.90	44.84	30.02	43.52				
<b>Bellary – Grade Medium</b>						4.32	0.61	0.92	10.31
Mean	23.42	12.33	7.34	32.38	32.38				
SD	5.81	2.28	2.78	15.72	15.72				
CV (%)	24.82	18.47	37.87	48.56	48.56				
$\Delta C$	-	-	-	-	-				
$\Delta H$	-	-	-	2.44	2.44				

L\* - Lightness, a\* - redness to greenness, b\* - yellowness to blueness, C - Chrome value, H – Hue angle;  $\Delta a^*$  - difference in redness/greenness,  $\Delta b^*$  - difference in yellowness to blueness;  $\Delta L$  - difference in lightness,  $\Delta C$  – difference in chrome value,  $\Delta H$  – difference in hue angle;  $\Delta E$  – Total color difference